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ABSTRACT

Techniques were developed for designing instruction for discipline-based curriculum areas. The apprcach integrated aspects of previous work in behavioral objectives, the structure of knowledge, learning hierarchies, and information-processing psychology and made explicit their relations to instructional design. Three kinds of analysis were involved: a) content analysis and cataloging of the conceptual systems of a discipline, b) task analysis of performance requirements for each type of conceptual system, and c) skills analysis of processes and strategies by which specific performance requirements can be carried cut. Use of the techniques has demonstrated their effectiveness in organizing content, identifying relevant tasks, and suggesting relevant empirical investigations. (Author)

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Techniques for Instructional Design

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Techniques for Instructional Design

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As the title suggests, this paper addresses the problems faced in planning the structure and content of an instructional program. Following the distinction between instructional design and instructional development, the techniques described here result in the specification and sequencing of what is to be taught but not in the specification of methods or materials to be used in instruction. The goal was development of techniques which would facilitate:

1. the specification of instructional objectives in terms of observable behaviors,
2. the maintainance of the integrity of source disciplines in the design of instruction, and
3. the formulation of research problems relevant to defined domains of instructional objectives.

The approach is eclectic, drawing on work in a number of related fields including the work of Schwab and Kuhn with structure of knowledge, the work of Gagne with learning hierarchies, and the work of Bruner, Ausubel, and others in cognitive and information processing psychology. The result, however, is an integrated framework within which the contribution of each field is made explicit.

The approach rests on the following assumptions:

1. Any discipline is built around a set of specialized conceptual systems.
2. Many of the specialized conceptual systems of a discipline fall into a small number of categories, each of which share a common logical structure.
3. Most important competencies related to a discipline, at least from a general education point of view, can be represented as manipulations of conceptual systems.
4. The level of mastery of a conceptual system may be adequately inferred from a defined set of observable behaviors.
5. Common information processing strategies are applicable to the utilization of conceptual systems sharing a common structure.
6. Appropriate instruction will produce significant transfer of learning across a set of conceptual systems sharing a common structure.

Briefly, the techniques involve analysis of content, tasks, and skills. Content analysis involves 1) the identification of the types of conceptual systems characteristic of a discipline or subdiscipline, 2) the formulation of a paradigm or analytic network which represents the structure of each type of system, and 3) the comprehensive identification and cataloging of the conceptual systems of a discipline according to the analytic network they exemplify.

Task analysis involves the identification of performance requirements relevant to a specific type of conceptual system. These requirements or tasks are described in terms of the corresponding analytic network.

Skills analysis identifies alternative information processing strategies by which tasks can be performed. These are descriptions of behavior at the psychological level and provide the basis for planning and predicting transfer among tasks.

The present approach is similar in several important respects to that of Gagne (1968, 1970). In particular, his notions of vertical and horizontal transfer of learning and of hierarchical organization of learning steps to optimize transfer have been a great influence. The importance he attributes to behavioral evidence of competence is also shared. However, two important features differentiate the present work from Gagne's. The first feature is the attention given to the knowledge structures of a source discipline and the second is the attention given to the information processing strategies by which an individual performs required operations or tasks. While these two features effect the approach to task analysis to some extent, they are reflected primarily in content analysis and skills analysis, respectively.

Content Analysis

The importance of basic conceptual systems or paradigms in the progress of a discipline has been convincingly argued by Kuhn (1962) and Schwab (1964). The "paradigms" or "substantive structures" give meaning, not only to laws and generalizations, but in many cases, even facts. They play a central role in the formulation of research problems and hypotheses. Ausubel (1968) has stressed the importance of "subsuming concepts" as a basis for further learning and an essential ingredient of problem solving ability. In a stimulating dissertation, Bowen (1972) integrates the work of Kuhn and Ausubel

and suggests that the paradigms which play such a crucial role in the advancement of knowledge in a discipline can play an equally important role in the advancement of learning in the individual. The present approach adopted a similar position as an assumption.

The design of instruction for curriculum areas based on disciplines (natural and social sciences, history, mathematics, music, art) must systematically deal with the conceptual aspects of those disciplines. In the present approach, this is accomplished through techniques for content analysis.

A discipline or subdiscipline is viewed as employing a number of basic conceptual systems. Furthermore, analyses to date (Smith and McLain, 1972; Piper et. al., 1972; Piper et. al., 1973; Greer, et. al., 1973) indicate that most such systems represent a relatively small number of different types of conceptual systems. The first phase of content analysis involves identification of the types of conceptual systems characteristic of a discipline or subdiscipline. This is accomplished by examining and comparing selected conceptual systems from a discipline. For example, classical mechanics deals with conceptual systems associated with force, distance, and time. Each of these systems involves a variable name ("force", "distance," and "time"), a set of descriptive values (n pounds, n feet, and n seconds where n is a member of the set of real numbers), and one or more standard measurement procedures for assigning values to the entities being described.

The second step in content analysis is the formulation of an abstract paradigm or analytic network which reflects the structure of a specific type of conceptual system. These networks consist of analytic concepts of which the specialized concepts are examples. As illustrated in Table 1, the analytic network for the mechanics conceptual systems mentioned above consists of the analytic concepts: variable name, values, observation/measurement procedure,

and elements (the entities characterized by the values of a variable). For clarity, the specialized concepts are referred to as systemic concepts and related sets of them as systemic networks.

TABLE 1

Components of the Variable-Value Analytic Network and Exemplary Systemic Networks

Analytic Concepts	Systemic Examples		
variable name	force	distance	time
values	n pounds	n feet	n seconds
observation/measurement procedures	use of spring scales	use of foot ruler	use of 1 second pendulum
elements	physical bodies	physical bodies	physical bodies

In the third phase of content analysis, the analytic networks are used to identify and catalog additional systemic networks in the area being analyzed. Analytic networks have been found very helpful in identifying and organizing content in complex areas such as music (Piper, et. al., 1973) art (Greer, et. al., 1973, Greer, 1974) and science (Smith, 1972). As explained above, the knowledge structures or content relevant to a curriculum area can be described at the analytic level and at the systemic level. Still another level of content is represented by the particular examples for use in instruction and evaluation. This third level of content called particular content is not needed for most design decisions. The time consuming and expensive task of identifying a sufficient quantity of particular content can be postponed until decisions have been made at the analytic and systemic levels. This order of decision making insures that particular content fulfills the design needs of the program and

avoids wasted effort of identifying irrelevant particular content. In current development activities, the particular content tail frequently wags the systemic and analytic content dog.

Analytic networks can play an important role in identification and organization of content for curriculum areas. As described in the next section, analytic networks can also play an important role in identifying, defining and organizing important competencies for curriculum areas. Potentially, however, the most important contribution of the theoretical framework just described is in the possibility that individuals can become skilled in learning and using types of systemic networks. Learning a series of systemic networks exemplifying the same analytic network suggests the possibility of the acquisition of learning sets or learning-to-learn abilities analogous to the phenomena familiar in experimental psychology. Psychological mechanisms by which such effects might be attained are discussed in the Skills Analysis section of this paper. Learning a series of parallel systemic networks also represents an instance where reception learning designed to facilitate "lateral subsumption" as described by Ausubel (1968) might be employed with considerable payoff. Analytic networks themselves might be made explicit and used as "advanced organizers" for sufficiently mature learners.

Task Analysis

Although the task analysis techniques might be thought of as dealing with the process aspect curriculum areas, the present approach brings a unity to the content-process distinction. It is assumed, and supported by the analyses to date, that similar operational requirements are relevant to each of a set of similar systemic networks. That is, operations or tasks relevant to a given systemic network (specialized conceptual system) are relevant to other systemic networks which are of the same type and are, therefore, represented by the same

analytic network. The tasks relevant to a set of systemic networks can be defined, abstractly, in terms of the corresponding analytic network. For example, the following task defines input-output requirements in terms of the variable-value network introduced above:

Given input:	A set of elements a value
Required Output:	An element accurately described by the given value.

This task can be applied to any of the set of systemic networks which exemplify the variable-value analytic network.

From this perspective, mastery of a process represents a type of mastery of a conceptual system. Conversely, any operational definition of concept mastery represents the specification of some process competency. Debate about content versus process becomes a question of what tasks should be mastered for what set of systemic networks. This is an important instructional design question which needs specific answers. Tasks and systemic networks related to a given analytic network can be represented in the form of a matrix (See Table 2). Each column represents a systemic network while each row represents a task.

TABLE 2

SAMPLE COMPETENCIES RELATED TO THE VARIABLE VALUE NETWORK
REPRESENTED AS A TASK-SYSTEMIC NETWORK MATRIX

Task	Systemic Network		
	Weight Network	Length Network	Frequency Network
Spatial Seriation			
Given: elements	G: set of objects	G: set of objects	G: set of oscillating systems
variable name	"weight"	"length"	"frequency"
Required: array of elements such that their spatial order corresponds to their order on the named variable	R: array of objects such that their spatial order corresponds to the order of their weights	R: array of objects such that their spatial order corresponds to the order of their lengths	R: array of systems such that their spatial order corresponds to their frequencies of oscillation
Sorting Variable Identification			
Given: groups of elements characterized by similar values of a variable	G: groups of objects of similar weight	G: groups of objects of similar length	G: groups of systems which oscillate at similar frequencies
Required: name of variable on which the elements are sorted	R: "weight"	R: "length"	R: "frequency"
Element Selection			
Given: elements	G: set of objects	G: set of objects	G: set of oscillating systems (e.g., pendula)
value	"n pounds"	"n feet"	"n cycles/second"
Required: element described by the given value	R: object which weighs n pounds	R: object which is n feet long	R: object oscillating at n cycles/second

Several techniques have been employed in developing tasks related to an analytic network. The explicit model represented by an analytic network has been found quite suggestive for persons knowledgeable in a subject matter area and familiar with the task-systemic network matrix approach. Such a person can frequently generate a substantial list of tasks. An heuristic that has been found useful involves generating pairs of combinations of analytic concepts. These pairs are then interpreted as given and required information for tasks. For example, the two combinations

variable name

observation/measurement procedure

and

elements

values

can be interpreted as the following task:

Given: variable name

observation/measurement procedure (directions)

Required: elements (identified by the learner)

values of the named variable describing each element

Some combinations may be meaningless or represent trivial tasks. It should be noted the professional judgment is involved in these decisions. Systematic analysis of the behavior of practitioners is another method for identifying tasks. Lists of objectives or problems produced using other approaches can, of course, be reviewed to identify tasks which may not yet have been defined within the framework.

In addition to their suggestive role in generating tasks, the use of analytic networks provides a standard means of defining tasks and a basis for organizing tasks (e.g., based on the kinds of information involved, the kinds of information given, or the kinds required). Defining a task in this manner is a much

broader contribution than preparing a specific objective since the task specifies a class of objectives, represented by the entire row of the task-systemic network matrix. Objectives specified at this level are adequate for most design purposes. They provide a basis for identifying relevant research findings as well as for generating research questions. Decisions about the general structure of a program do not require specification of objectives as detailed as those advocated by Mager (1962) and others. In fact, objectives so specified tend to obscure substantive relations among objectives. They are also rather cumbersome and difficult to organize. After certain cells of the matrix have been selected, the job of specifying particular content, constructing test items, and establishing performance criteria can be carried out (see Piper, 1974). Each selected cell becomes a focus for development of a pool of test items (or practice problems). Item form procedures (Hively, et. al., 1968; Osborn, 1968) and item-pupil sampling techniques (Shoemaker, 1973) can be readily applied at this stage. Note, however, that these expensive tasks need be undertaken only after the substantive framework of the program has been designed. The same arguments apply to systematic research over a task-systemic network matrix.

A matrix of the form described above defines a domain within which a learning heirarchy (Gagne, 1968, 1970) might be developed. The task-systemic network unit represented by a cell seems to correspond fairly closely to the "single capability" represented by a box in a Gagne heirarchy. Furthermore, facilitation of learning resulting from prior learning represented by cells in the same column or row, correspond closely to Gagne's notions of vertical and horizontal transfer, respectively. Such effects are an important consideration in the present approach as they are in Gagne's. However, the techniques proposed here for planning to optimize transfer go considerably beyond those suggested by Gagne. These techniques are called skills analysis and are the topic of the next section of this paper.

Skills Analysis

Task analysis results in the identification of tasks relevant to systemic networks of a given type. The term "skill" as used here refers to an inferred psychological process involved in the pe formance of a task. The analysis of skills with which tasks may be performed, is called skills analysis.

Although operational definitions of skills as abilities to perform given tasks are useful, and perhaps even necessary for program evaluation and student assessment, they are inadequate for designing instructional programs. Different individuals may learn to perform the same task in quite different ways. The classic studies of the "concept attainment" task (Bruner, et. al., 1956) for example, demonstrated that while most learners adopted a relatively stable strategy for performing the task, several quite distinct strategies were found. The transfer effects of learning several tasks probably depend heavily on the strategies the student learns to use in performing both original and transfer tasks. This suggests that the design of instruction to optimize positive transfer must consider the strategies which the student learns to use in performing the tasks included in the program. The work of Resnick (1967) is in this direction. A more complete discussion of the need for a more powerful approach to skills analysis is presented elsewhere (Bessemer and Smith, 1972).

In the present approach to skills analysis, one or more information processing models for each task are prepared incorporating carefully selected strategies. On the basis of the models, tasks and systemic content are sequenced to promote systematic development of the strategies in the learner. It is assumed that instruction developed on the basis of such models and following the instructional design will result in behavior consistent with the models and produce substantial transfer effects. As a student learns to use a strategy to

perform a task with a series of similar systemic networks, a representation of the strategy becomes available in long term memory thus facilitating subsequent learning with additional systemic networks. This represents lateral transfer and is analogous to the phenomenon of learning set acquisition studied in experimental psychology (e.g., Bessemer and Stollnitz, 1971).

Strategies are potentially a mechanism for vertical transfer as well. Once a strategy for a task has acquired some degree of stability, it can function as a subroutine in a larger strategy for performing a more complex task. Obviously, the utility of the simpler strategy depends on its compatibility with the higher level strategy. It is assumed that something like this occurs whether or not it is planned. This explains the importance attached to careful selection of strategies and sequencing of tasks in the present approach. One task may or may not be prerequisite to another, and thus facilitate its learning, depending on the compatibility of the strategies an individual learns to perform them.

A skills analysis was carried out on fifteen selected tasks defined in terms of the variable-vaiue analytic network (Smith, McClain and Kuchenbecher, 1972). The information processing models were in flow chart form similar to those constructed by Klahr and Wallace (970) in a study of Piagetian tasks. An information processing model for the spatial seriation task is illustrated in Figure 1. The rectangular boxes represent, for the purposes of the analysis, unitary skills or primary processes. These are defined in terms of their input and output of information and the nature of the operation transforming the information. (See Table 3). Square boxes such as the one in Figure 1 calling for the performance of MAXPIC represent secondary or tertiary processes which are defined in terms of other processes. The strategy employed in the model in Figure 1 involves finding the unordered object representing the maximum value on the seriation variable, placing it next in the row, and repeating the cycle

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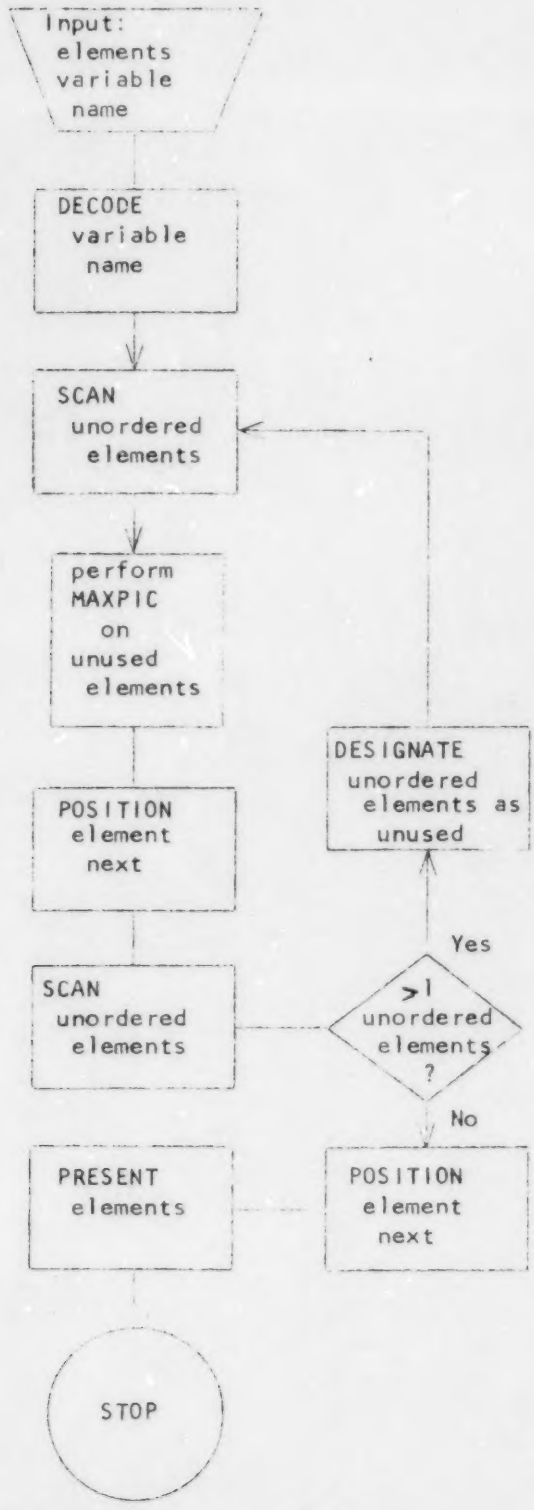

Figure 1--Maximum Value Selection Strategy for the Spatial Seriation Task

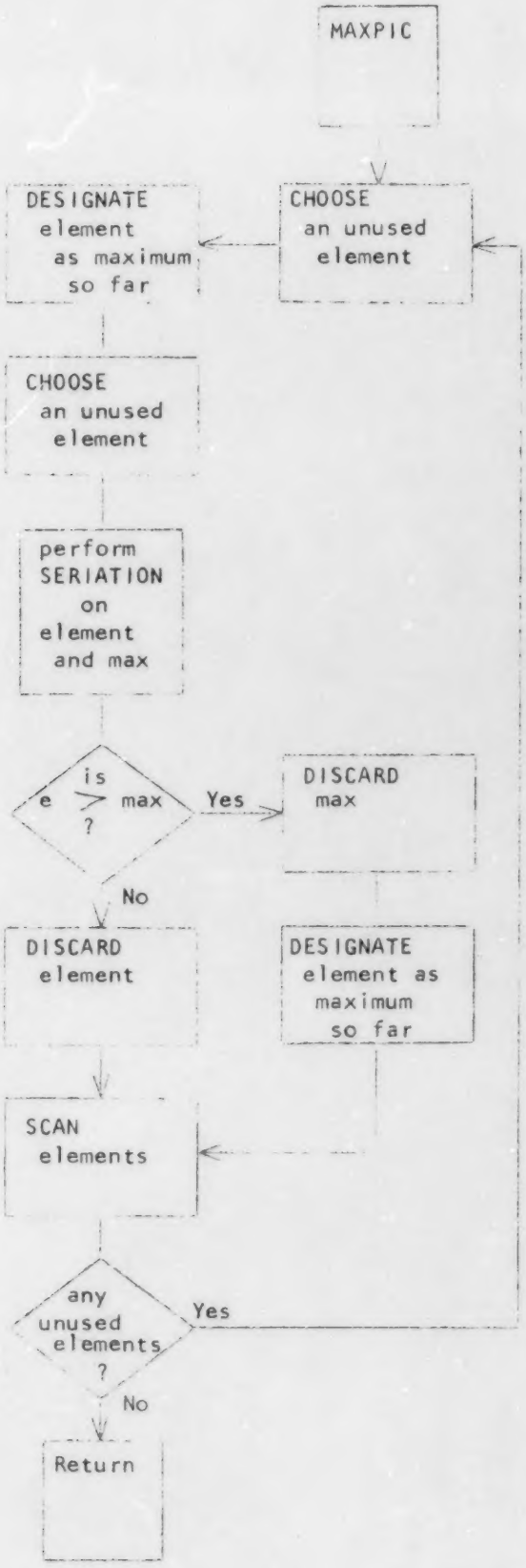

Figure 2--MAXPIC Tertiary Process

TABLE 3

INPUT AND OUTPUT CHARACTERISTICS OF PRIMARY PROCESSES

Primary Process	Input	Output
DECODE*	verbal label for a concept	a concept (activated)
SCAN	undifferentiated stimulus information	one or more differentiated perceptual objects
CHOOSE	a set of previously differentiated stimulus objects	an object which becomes the focus of attention
DISCARD	an element currently attended to with a negative result from the application of the criterion for set membership	given element in a periferal spatial location
POSITION	an element; a set of ordered elements with one or two distinguished as a reference; an ordinal concept relating new and reference elements	a set of elements with the original order preserved and the new element properly positioned with respect to the reference element(s)
PRESENT	an element or set of elements which are the output of previous processing steps	verbal or nonverbal gesture identifying the elements
DESIGNATE	an element or set of elements; role concept	ar element or set of elements to be used in that role

*A more complete description of the DECODE primary process is presented here as an example.

DECODE is the primary process by which an associative network is entered by way of a verbal label for one of the constituent concepts. The input for the process is the verbal label. Decoding of the label results in the activation of a concept or node in the network. This does not necessarily result in the reconstruction of images, actions, or verbal entities. In effect, the DECODE process opens the way to many possibilities, but it remains for the next step(s) to take advantage of one or more of them. The possibility that the individual is set to perform another step which then follows automatically from the decoding need not concern us here. The point is that access to the storage network must be gained as a result of processing the verbal label. This is the function of the DECODE process.

until all the objects are ordered. The MAXPIC tertiary process is used repeatedly to pick the object with the maximum value on the input variable from among the input set of objects (See Figure 2).

Processes which occur in the models of many tasks represent important foci for basic research. In the skills analysis referred to above, one secondary process (COMPARISON) was employed in the models developed for all fifteen tasks. The important role played by this secondary process led to initiation of further study of its component processes (Bessemer, 1973; Fisher and Bessemer, 1974; Coots, 1973a; Coots, 1973b.)

Recent empirical investigations conducted by the writer found that about 25% of a group of 96 first grade children from urban elementary schools employed some form of an extreme value selection strategy to spatially seriate sets of 4 to 10 objects on length or weight. One child used a strategy completely compatible with the model. Several others deviated only in not discarding (setting aside) observed objects. About 10% of the children, however, used an entirely different strategy, inserting objects at any point in the ordered row.

Experimental studies planned for the near future include investigation of instruction designed to facilitate the learning of specific strategies for the seriation task. One approach will involve embedding the MAXPIC tertiary process in the strategy for a simpler task in which the child is required only to find the element with the greatest value on a particular variable (e.g., heaviest). This illustrates one role that skills analysis, as presently conceived, can play in the development of learning hierarchies. Other studies will investigate the vertical and horizontal transfer of strategies, the interaction of individual difference variables with the learning of alternative strategies, and the relation between strategy utilization and developmental level.

Conclusion

While many of the ideas incorporated in this paper are not new, they are presented here in a form which makes explicit their relationship to instructional design. Bringing them together has suggested interrelationships among them previously unrecognized or undeveloped. The learning hierarchy approach of Gagne has lacked a formal model for relating operationally defined competencies to the conceptual structures of disciplines and an approach for modeling the processes and strategies involved in task performance. Conceptually oriented instructional programs have failed to operationally define conceptual mastery, and analyses of cognitive processes and strategies have seldom involved tasks derived from school learning problems. The present efforts have attempted to bring these diverse elements together into an integrated framework for instruction design and related research. The work reported here is only a beginning. It is hoped that this framework and the techniques described will generate considerable further inquiry.

It should be pointed out here that while the techniques described above for content and task analyses have been applied with success in the design of instructional programs, skills analysis has been carried out only on a limited basis. Furthermore, empirical investigation of the feasibility of obtaining the intended effects has only begun. However, the potential payoffs in facilitation of conceptual learning and in teaching complex problem solving and independent learning strategies seem well worth considerable effort in exploring this approach.

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